

The Control of Multi-Agent Systems (MAS)

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Approaches to Organizations

- **Logical “methodological individualism”** (Nowak & Sigmund, 2004)
 - Darwin, Von Neumann
 - Allport (1922): “Groups” do not exist
 - **Assumption: Reality is stable with *I* that is mostly accessible**
- However, “contradictions do not exist in nature ... [but are] unavoidable ... within formal frameworks” (Tessier et al., 2000, p. 24)
- **Mathematical physics of Organizations**
 - Allport (1962): The major unsolved problem in social psychology is the shift from individual to group member
 - Lewin (1951): a group is more than sum of parts
 - Luce & Raiffa (1967): individual rational perspective cannot account for the “social” (viz., game and decision theory)
 - Kelley, 1992, **Measurement problem**: self-reported preferences (given matrices) \neq choices enacted (effective matrices)
 - Active, passive deception
- **Assumption: Reality is bistable with *I* that is mostly inaccessible**

Paradoxes

- **Rational, Individual:** $\sum x_i$ d.m. \neq consensus (CR) (Arrow's Impossibility Theorem); Nash's possibility of bargaining theorem within CR
 - **CR \rightarrow individual rationality** (Group d.m. $\rightarrow \sum x_i$)
 - **CR: nothing wrong with arriving at consensus, but consensus-seeking \rightarrow groupthink** (Janis, 1982)
- **Rational, Organizational:** surveys \neq groups (Levine & Moreland, 1998)
 - Adam Smith's "invisible hand" \Rightarrow competing groups easily resolve rational paradoxes
 - **M problem: $M(\text{Group}) \rightarrow$ individual (classical) I**
- **Rational individual d.m. \neq group d.m.**

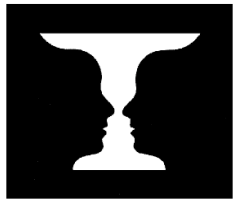
Yet current MAS's use rational **individual cooperative** agents for groups

When Cooperation Works	When Cooperation Does Not Work
The evolution of cooperation may preclude nuclear war (Axelrod, 1984)	<ul style="list-style-type: none"> • Social loafing (Latane, 1981) • Asymmetric <i>I</i> (terrorism, corruption, blackmail) • Computational blowup as <i>N</i> cooperating agents exceed 100 (Darpa, 2002)
Cooperation requires constraints such as coercion (Axelrod, 1984; Hardin, 1968)	<ul style="list-style-type: none"> • Coercive gov't reduces social welfare (Hayek, 1944) • However, Axelrod's claim is true if meaning of "cooperation" is reversed
Cooperation under single WV implies that "moral" judgments reject compromise to reduce bloodshed (Worchel, 1999)	<ul style="list-style-type: none"> • Government by Consensus <ul style="list-style-type: none"> ○ Japan: Unable to reform ○ Germany: More Corrupt (TI, 2002); Tietmeyer (2002), ex-president Bundesbank, "... what we need are majority decisions ... [not] consensus"; however, in 2004, Siemens breaking union's grip. ○ WTO collapse in 2003 attributed to consensus d.m. (CDM): "almost impossible for the 146 nation group to reach agreements." (WSJ.com)
Mathematically, less diversity => + stability (May, 2001, p. 174) <ul style="list-style-type: none"> • e.g., single WV, gender, race, religion, and polity -> + stability • => consensus-seeking & dictatorship (Lawless & Schwartz, 1992) 	EC: "The requirement for consensus in the European Council often holds policy-making hostage to national interests in areas which Council should decide by a qualified majority." (WP, 2001, p. 29)
Solving well-defined problems (<i>wdp</i> 's) (Lawless et al., 2000b)	Solving ill-defined problems (<i>idp</i> 's) (Lawless et al., 2000a)



Research Impetus: Control of Robot Organizations -> Autonomy

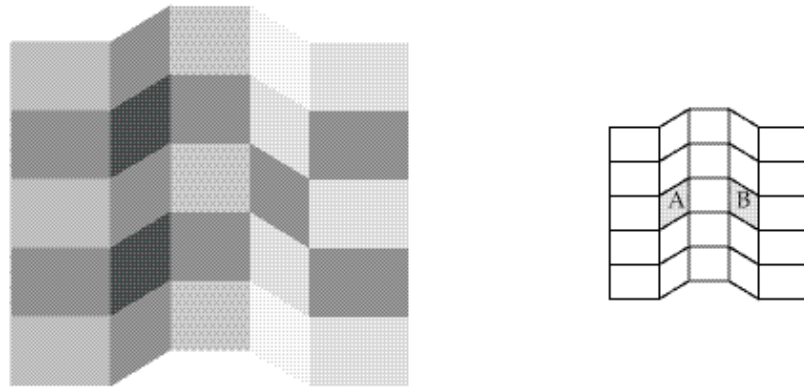
- Organizations based on “methodological individualism”:
 - Bankes (2002): validating social ABMs not possible
 - Tambe (2003): ABM autonomy currently not possible
 - 5-6 humans per Predator w/staff of 20 (Russ Richards, JFC, 2003); 4 airborne over OIF (Moseley, 2003)
 - DARPA: Organizations \approx 1 soldier + R2D2 + 300 less-intelligent agents w/“live weapons”
 - However, politically, swarms will not go “live weapons” w/o autonomy validation
- Organizations based on bistability:
 - **If M(bistable MAS) -> classical *I*, can it be controlled?**



Bistable $R \Rightarrow$ Multiple Frames for a single context

1. Physically: Organism exists simultaneously **superimposed** as
 - Observer and actor
 - Individual organism and member of a group
 - Member of a group A and group B
2. Bistability \rightarrow constructive-destructive interference patterns
 - bistability suppressed under obedience, strong beliefs, or conformity
3. Organization = Σ entangled (correlated) individuals
4. Observer: Object acquisition + $E \rightarrow$ convergence (γ waves or feature binding)
 - (K&T, 1981): “Framing” \rightarrow convergence of beliefs, - dissonance; e.g., “culture A” (Bohr, 1955)
 - Participants perceive “frame” A or B, but not both (Cacioppo et al., 1996)
 - Opposite K&T frames \rightarrow tension, disagreement, or conflict (Janis, 1982)
5. **H: Managing opposed frames = argument \rightarrow optimal d.m.** (Lawless & Schwartz, 2002)

Characteristic bistable phenomena: Illusions, conflicts, multiple interpretations, multiple justifications



- AI cannot resolve illusions (Brooks, 2003)
- The traditional belief that rational decisions (CR) are superior to democracy is an illusion (Benardete, 2002)
- Perception of reality may be a quantum illusion (Bekenstein, 2003)
- **Yet, humans resolve bistable reality into classical *I*** (Cacioppo et al., 1996)

What could a Computational Model of Bistable Reality Mean?

- Feynman (1985) found:
 - Traditional computers model quantum R inefficiently
 - Quantum computers model QR efficiently
- Can bistable ABM's efficiently model SR
 - Traditional models are inefficient
 - H: Bistable models \rightarrow efficiency, power \Rightarrow SIP
(Lawless & Grayson, 2004a)

Hard Problem, but support exists for a social bistable (quantum) model

Action-observation uncertainties -> multiple interpretations -> multiple cultures	Bohr (1955)
Differences between definitions and word use	Heisenberg (1999)
Humans can focus on only one aspect of an object at a time; convergence increases outgroup uncertainty	Gibson, 1986; Tajfel, 1970
Quantum human hearing model is an acceptable alternative to classical SDT; i.e., either a) Bèkèsy-Stevens discrete E levels; or b) Swets ROC YY-YN curves.	Luce (1963), <u>HMΨ</u> . Luce (1997). "Several unresolved conceptual problems of mathematical psychology." <u>Journal of Mathematical Psychology</u> 41 : 79-87.
Measurement changes the properties of what is measured.	Lipshitz, R. (1997). Naturalistic decision making perspectives on decision errors. <u>Naturalistic decision making</u> . C. E. Zsombok & G. Klein. Mahwah, NJ, Lawrence Erlbaum: 49-59. Carley, DNA analysis (R. Breiger, K. Carley, & P. Pattison, <i>Ed.</i> , Committee on Human Factors, NRC, forthcoming)
Superposed data forms robotic social maps of the physical environment	Zlot, R., Stentz, A., Dias, M.B., & Thayer, S. (2002). Market-driven multi-robot exploration (CMU-RI-TR-02-02).
The eye is a quantum I processor; all reality is an illusion .	French & Taylor, 1978; Bekenstein, 2003

CIP versus QIP (Bistable)

- Classical I is either 0 or 1 = bits
- **Exponential increase in CIP \Rightarrow exponential increase in processors and physical space** (e.g., $n \times n = n^2$ processors)
- Quantum I is simultaneous 0 and 1 = qubits $\Rightarrow 2^n$ values
- **Exponential increase in QIP \Rightarrow a linear increase in processors and physical space** (e.g., each $n \Rightarrow 2^n$ processors)
 - Superpositions (linear combinations) can evolve (Feynman) and explored (Deutsch)
 - QIP: solutions derived from constructive interference; M destroys superposition
 - + QIP w/ + T (Lloyd, 2000) \approx emotion for humans & organizations

Measurement Problem: $M(I,S) \rightarrow$ classical I

- An undecided single agent exists in a superposition of two complex states $\alpha|\uparrow\rangle + \beta|\downarrow\rangle$, w/prob(\uparrow) = α^2 , prob(\downarrow) = β^2 , giving $|\alpha|^2 + |\beta|^2 = 1$
- Superposition corresponds to average of E_0 and E_I ;
 - Mixes rational (ground state $E_0 = |\downarrow\rangle$) & emotional (excited state $E_I = |\uparrow\rangle$)
- **$M(I, S) \rightarrow$ shifts agent $|\uparrow\rangle$ or $|\downarrow\rangle$ w/P(1)** (Gibson, 1986; Caccioppo, 1996) **\rightarrow increases entropy, but once classical I it remains classical** (Physics Today; Luce) until re-entangled as (I,S)
- Thus, $M(I, S) \rightarrow$ stable Event Histories \neq reconstruct atomic (Zeilinger, 1999), individual (Baumeister, 1995) or social phenomena (Levine & Moreland, 1998; Eagly & Chaiken, 1993; Carley, 2003)

M(Group, Superposition) -> classical I

- Entanglement => feedback is stronger than context
- Given 2^n states, the superposed “extra” states have no classical analog, producing the EPR paradox
- Basis 2-undecided agents: $\{|\downarrow\downarrow\rangle, |\downarrow\uparrow\rangle, |\uparrow\downarrow\rangle, |\uparrow\uparrow\rangle\}$
=> $2^2 = 4$ states; basis for 3 agents => 2^3 states
 - Non-entangled state: $1/\sqrt{2} (|\downarrow\downarrow\rangle + |\downarrow\uparrow\rangle) = \text{decomposes}$
 - Entangled state: $1/\sqrt{2} (|\downarrow\downarrow\rangle + |\uparrow\uparrow\rangle) \neq \text{decomposed}$
 - $M(|\downarrow\downarrow\rangle + |\uparrow\uparrow\rangle) \rightarrow |\downarrow\downarrow\rangle \text{ or } |\uparrow\uparrow\rangle \text{ with } P(1)$
- **The entangled state $|\downarrow\downarrow\rangle + |\uparrow\uparrow\rangle$ cannot be decomposed into classical components => no intuition** (Rieffel & Polak, 2000, ACM, 32(3), p. 308) **nor meaning => convergence** (Campbell, 1996)
- **H: The “social” state of 2 neutral, entangled agents cannot be decomposed** (Lawless & Grayson, 2004a)

Mathematical physics model of Bistable Uncertainty = H.U.P.

- Let $K = f(x)$; ΔK = belief uncertainty = I (Shannon's I);
 - $K = f(x) \approx f(\text{group, experience, location})$ (Latane, 1981; Tajfel, 1970)
- Let $\Delta v = \Delta (\Delta K / \Delta t)$ = action uncertainty;
$$\Delta v \Delta K \geq c \quad (1)$$
- **USAF:** Traditional SLT \Rightarrow L improves skills; however, in combat pilot experiment, book K ($\Delta K \rightarrow 0$) did not predict wins-losses, E availability, or expert ratings, but training did ($\Delta a \rightarrow 0$) (Lawless et al., 2000a)
- **DOE:** SRS CAB (majority) v HAB (consensus): “competition of ideas” ($\Delta K \rightarrow \infty$) improved nuclear waste cleanup + trust
- **Nations:** May's 1997 data base: competition between nations increased SW, H, E, EF, and trust while reducing corruption (Lawless et al., 2000b)
- **Computational:** Expert forecasters best over short term, CCFP close 2nd and better over longer term, NCWF worst

Decision-Making: Conclusions

- If Bistable R exists, orthogonal operators and neutrals produce optimal solutions to decisions for idp 's, driving social evolution (Lawless & Grayson, 2004a)
 - Truth-seeking: idp 's best w/competition
 - + competitive nations \rightarrow + SW (creativity), H, E, trust and - corruption
 - Overheating \Rightarrow open conflict, war
 - Consensus-seeking: wdp 's best w/cooperation
 - Underheating \Rightarrow corruption, low creativity
 - **Resonance** (??) and social barriers

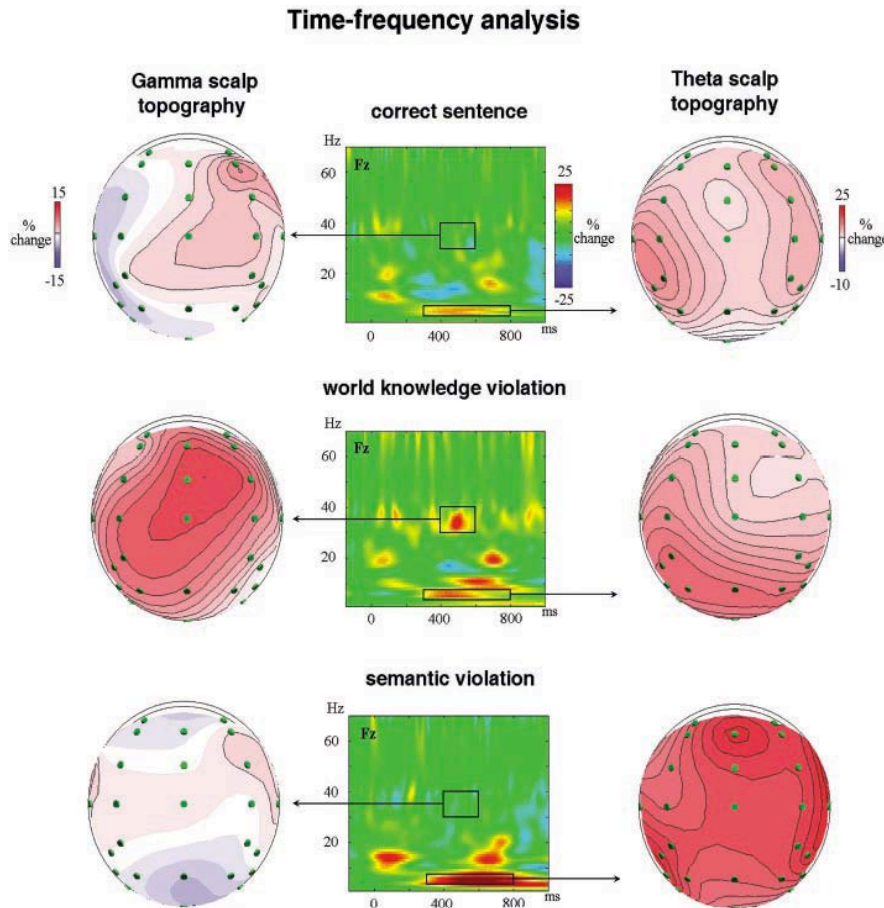
Revising Equation (1) -> H.U.P. for social χ

- Given reactance, j , $\Delta v \Delta K = \Delta (\Delta K / \Delta t) \Delta t / \Delta t \Delta K = j \Delta (\Delta K / \Delta t)^2 \Delta t$, giving
- $$\Delta v \Delta K = \Delta t \Delta E \geq c \quad (2)$$
- Case iii: $\Delta t \rightarrow 0$, $\Delta E \rightarrow \infty$ (e.g., big court cases & science)
- Case iv: $\Delta E \rightarrow 0$, $\Delta t \rightarrow \infty$ (e.g., vocal resonance)
- Human cognition
 - 40 Hz Gamma waves (object binding) ≈ 75 -150 ms
 - 16 mm movie film ≈ 62.5 ms
 - $\Delta t \Delta E \geq c = \Delta t \Delta h \omega = h$
- See Slides 16, 17:

Brain Wave Evidence for Equation (2) and H.U.P.

correct: The Dutch trains are yellow and very crowded.
 world knowledge violation: The Dutch trains are white and very crowded.
 semantic violation: The Dutch trains are sour and very crowded.

K conflicts: EEG data adapted from Hagoort et al., 2004, *Science*, 304, 438-441, Fig. 2 [Note: 29 EEG recordings per subject, 30 subjects].



• **Gamma Waves (feature binding):** $\Delta t = 1/\Delta\omega = 1/(40 \text{ Hz}) = .025 \text{ s} \geq 25 \text{ ms}$

<-- EEG data $\approx 50\text{-}75 \text{ ms}$

• **Theta Waves (episodic and working memory tasks):** $\Delta t = 1/\Delta\omega = 1/(5 \text{ Hz}) = .200 \text{ s} \geq 200 \text{ ms}$

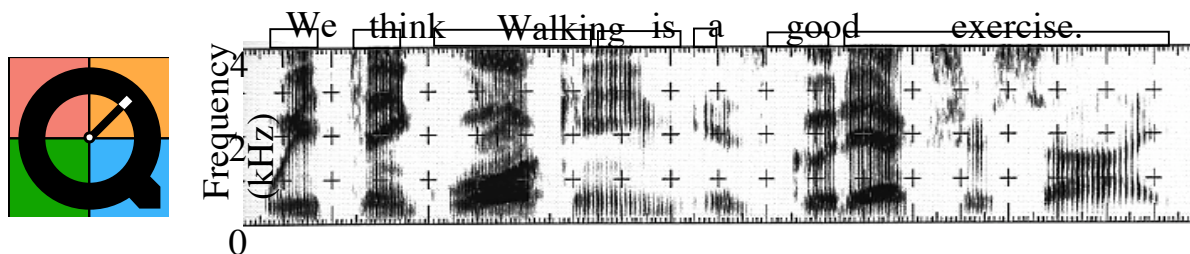
<-- EEG data $\approx 3\text{-}400 \text{ ms}$

• $N = 30 \Rightarrow c = h$ for groups

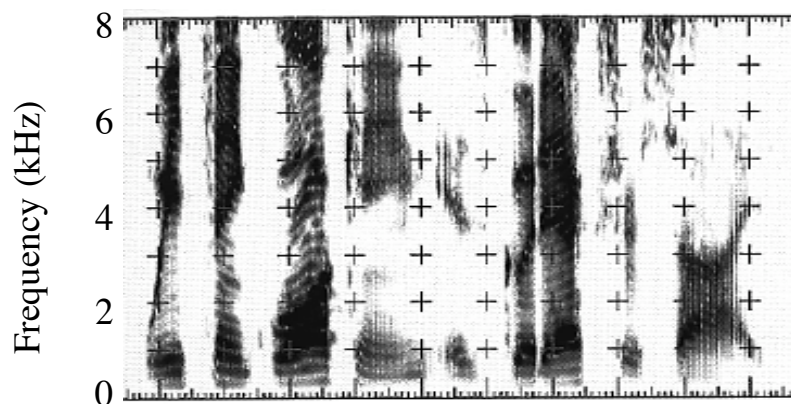
• **Exposure to the same visual context (movie) synchronized individual brain patterns** (Hasson et al., 2004, *Science*, 303, 1634)

Audio demonstration of Equation (2) (H.U.P.)

3 sentences at normal speed



Same 3 sentences at 100%
faster (i.e., $\Delta t/\Delta t_0 = 1/2$)



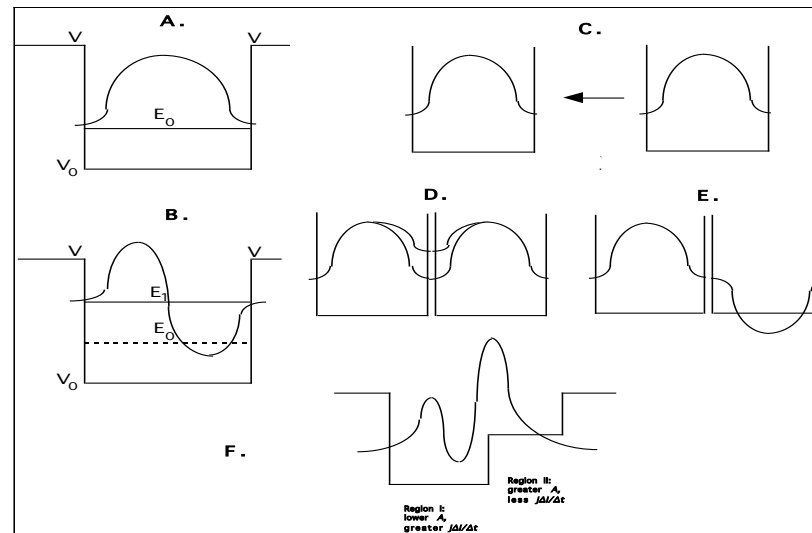
But, by playing back in 1/2 time,
 E doubles (i.e., ω) = H.U.P.

- *Given $\Delta\omega\Delta t = 1$*
- $\Delta\omega = 1/\Delta t = 1/(1/2)$
 $= 2 \text{ Hz}$

Source: Kang, G.S. & Fransen, L.J. (1994), Speech analysis and synthesis based on pitch-synchronous segmentation of the speech waveform, NRL Report 9743 (kang@itd.nrl.navy.mil).

Community Set-Point Theory: ($K = f(x)$; Latane, 1981). Square wells of E form emotion = set points \Rightarrow SPT (e.g., food, lotto; Diener & Oishi, 2000). Baseline E_0 associated with emotion potential energy, V . As excitation E attempts to redefine meaning, V keeps beliefs stable. C, D, E: Groups. C-D illustrates E_0 , D-E shows first excited state, E_1 . F. Experts at I, Novices at II

(Landers & Pirozzolo, 1990; Lawless & Chandrasekara, 2002)



Conclusions:

- 1st model of a group $\neq \Sigma$ disaggregated individuals
- Models experts versus novices
- Models mixed E levels for groups

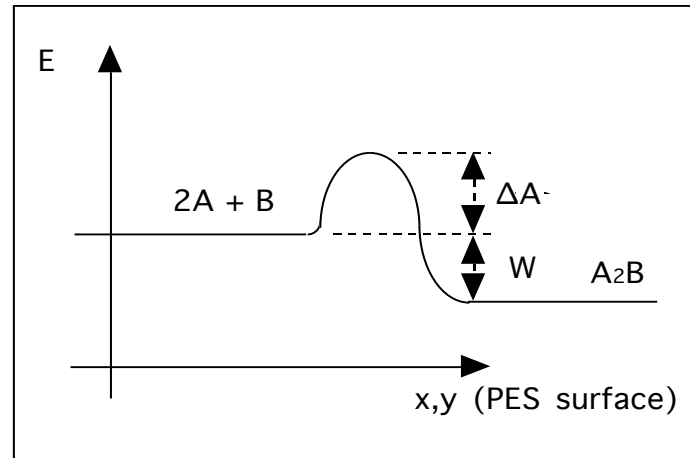
ΔK -DFT (organization, mergers, and K)

- $E^{PES}(x,y) = \min_{z,R_{org}} E^{TOT}(x,y,z,R_{org})$ Sallach (2002) (3)
 - Function, hierarchy, organization (Sallach, 2002) => **Hamiltonian** (Lyapounov)
- $H = H_0 + H_{int}$ (4)
 - $H_0 = E_b^A \sum_k n_k + E_b^B \sum_k m_k + V^{A-B} \sum_k n_k m_k$ (0 if empty, 1 if occupied)
 - $H_{int} = 1/2 V_{1n}^A \sum_{k,a} n_k n_{k+a} + 1/2 V_{2n}^B \sum_{k,b} n_k n_{k+b} + 1/2 V_{1n}^B \sum_{k,a} m_k m_{k+a} + 1/2 V_{2n}^B \sum_{k,b} m_k m_{k+b} + 1/3 V_{trio}^B \sum_{k,a,a} m_k m_{k+a} m_{k+a} + \dots$

Conclusions:

- W/growth heterogenous island stresses reduce from Hi to Low (**terrorism**)
- Utility theory for organizational χ 's: $\Gamma_P = n_A n_B v \sigma_{AB} \exp(-\Delta A/k_B T)$ (5)
 - Barriers (constraints) must be overcome for an interaction to proceed
 - Winners & losers = $f(N) = \#$ of fourier components
- **Cross-section affects rate of χ : $\sigma_{AB} = \alpha_\chi (\omega^4/(\omega^2 - \omega_0^2)^2)$** (6)
 - Clinical matching (experience & treatment) => **resonance** = HXS
 - Friends \approx vocal harmonic oscillators => **resonance** = HXS
 - terrorists seek a LXS w/cooperation => **reactance** \approx 1/**resonance**
 - Lengthen interaction to expose and exhaust terrorists

Perturbation Theory (explains why $\sum x_i$ in g.t. \neq organization)



(Lawless & Chandrasekara, 2002)

1. Mergers require $E(\Delta A)$ (Lawless & Grayson, 2004a)

2. Once organization forms $\rightarrow E_{min}$:

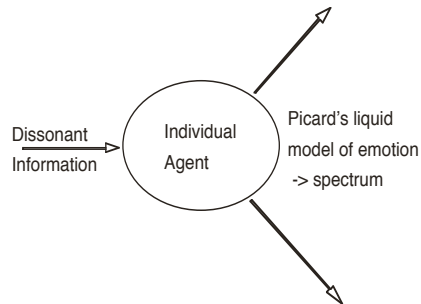
- Social Loafing (Latane, 1981)
- Audience Skills enhancement (Zajonc, 1998)
- Terror Mgt (Rosenblatt et al., 1990)
- Health (House et al., 1988)

3. $E_{min} \Rightarrow$ Perturbation Theory (Lewin, 1951)

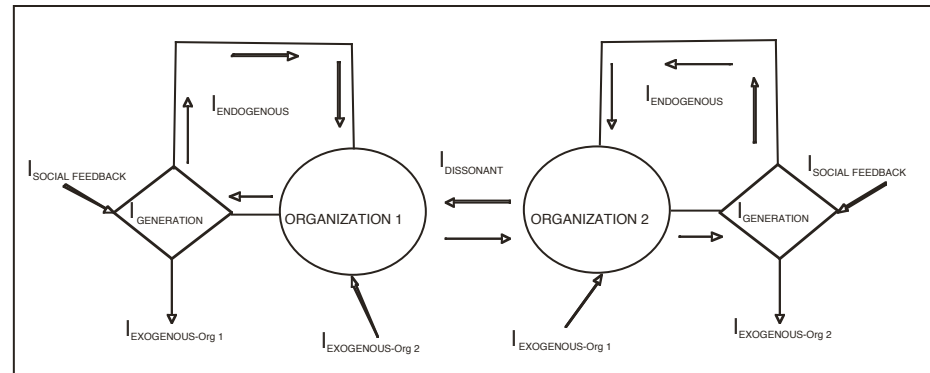
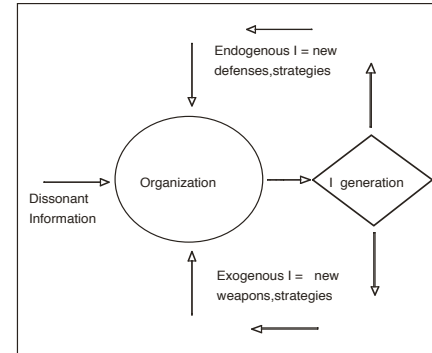
- Attacks against Afghanistan and Iraq gained I (Feitz, 2004, Ass't Sec. Def.)

3-D Perturbation Model of Game Theory

$\Delta E \approx h * \Delta v$ (Penrose: 40 Hz, gamma; Hagoort, 2004: 5 Hz, theta)



$\Delta E \approx h * \Delta v$ (Kang: Anger $\approx + 100$ Hz)



H: With perturbations, strategy (ΔK) and speed to enact strategy (Δv) determine outcomes:

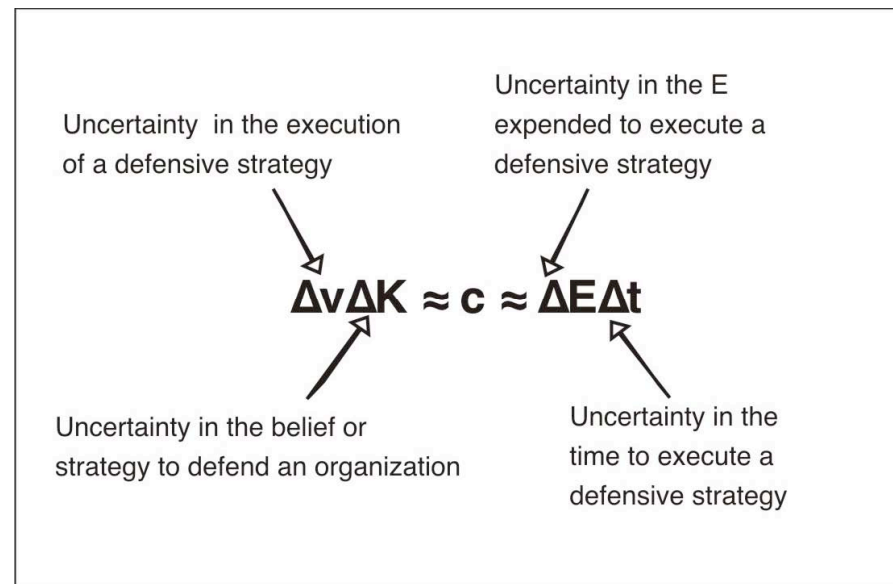
- Strategy: PeopleSoft, a business software company merging w/JDPower and threatened w/hostile takeover by Oracle, implemented poison pill defense by invoking antitrust law; Oracle changed its initial hostile offer from stock only to stock + cash.
- Speed: In the 2003 war with OIF, coalition d.m. and execution was faster than Iraq's Defense Forces, causing the latter to panic (Franks, 2004; Kagan, 2004; Lawless & Grayson, 2004b).

9th ICCRTS,
Copenhagen, 9/2004

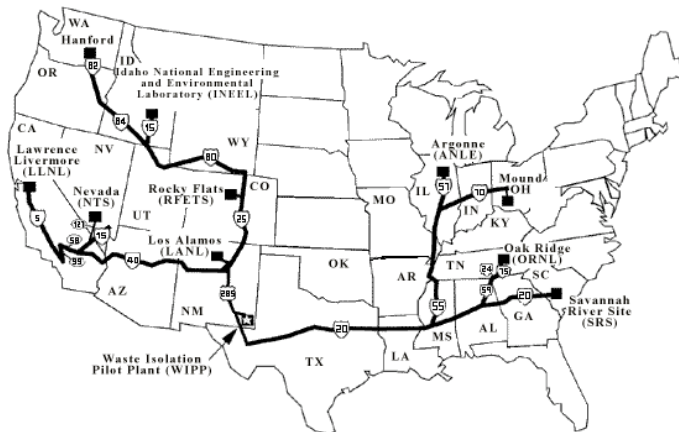
Perturbation conclusions

- **1st Mathematical demonstration that organizations under attack coalesce** ($E = f(\omega) = f(1/\lambda) \Rightarrow$ tighter, agitated, cooperative groups (Rosenblatt et al., 1990))
 - Ants (May, 2001) & Slime Molds (Nicolis & Prigogine, 1989)
 - Iraqi Defense Forces (Kagan, 2004); Terror impacted elections in Spain and Israel, 2004
 - Corporate mergers (Lawless & Grayson, 2004b)
 - Transformation strategy success: + # Fourier elements
 - Perturbations \Rightarrow coupled oscillators
- If $\rho = K/V$ (Glaeser, 1996), from continuity $\partial \rho / \partial t = -\nabla \cdot (\rho v)$
 - $F = -\nabla(K \text{ potential}) \rightarrow 0 \Rightarrow$ structures, channels
- **However, attacks generate the M problem**
 - (M bistable $I \rightarrow$ classical I)

Prelude to Control: Perturbations exploit Measurement problem (e.g., hostile merger of PeopleSoft and Oracle)



- DOE Tru waste repository opened at WIPP in 1999
- Secretary Roberson calls for acceleration in 2002
- NAS (1/04) -> M (field test)



TRU: Radioactive waste contaminated with uranium 233 or elements beyond uranium on the periodic table and existing in concentrations of more than 1 ten-millionth of a curie per gram of waste. These isotopes, mostly pu-239, have half-lives of over 20 years and are all manmade.

clinton2.nara.gov/OMB/inforeg/glossary.html



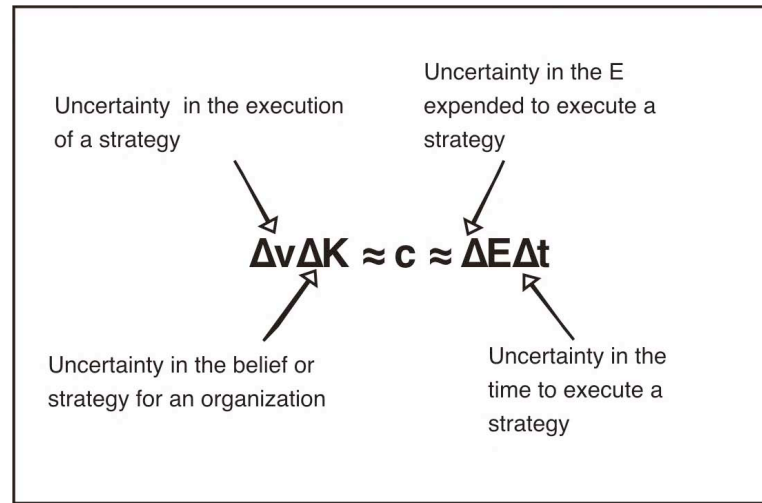
M (field test): In 2003, 13 Recommendations by DOE Scientists to Citizens (N=105) for approval to accelerate disposition of Transuranic wastes to WIPP, NM

- DOE characterize TRU waste as required to reduce risk and minimize transportation and handling of waste while making confirmation process cost effective
- Therefore, to meet Site Specific needs, DOE allocate and coordinate resources complex-wide to optimize shipping to maximize the receiving capacity of WIPP
- DOE in concert with stakeholders and regulators initiate an ongoing program to identify, correct and revise those requirements that interfere with the safe, prompt and cost effective management of TRU waste
- DOE identify volumes and disposition pathways for all potential TRU waste streams
- DOE in consultation with stakeholders and regulators initiate action to assure that WIPP has the capacity to accommodate all of the above listed TRU waste
- DOE accelerate TRU waste container design, licensing and deployment
- DOE streamline TRU waste management by accepting demonstrated process knowledge for TRU waste characterization
- **DOE, in consultation with stakeholders and regulators, reexamine the categorization of TRU waste using a risk-based approach**
- DOE identify the inventory of orphan TRU waste and assign a corporate team to identify a path forward
- DOE evaluate the concept of one or more locations to characterize TRU waste for WIPP disposal
- DOE finish its analyses and make a decision with adequate public involvement regarding where to characterize TRU waste for disposal
- DOE expedite the design, fabrication and certification of container transport systems Arrowpak and TRUPACT III and accelerate the adoption of rail transport as appropriate
- DOE revitalize its efforts in coordinating its transportation issues with States and Tribes and assist in updating and disseminating information to the public about transportation risks and safety and provide public participation opportunities on transport issues

M (field test): In 2003, Representatives (N=105) of 9 Site Specific Citizen Advisory Boards (SSAB's) (total N=250) associated w/DOE Sites met to decide on scientific recommendations

Active SSAB's (N = 9; about 250 members total)	Decision Process	Inactive SSAB's (N = 3)	Decision Process
Fernald	CR	Pantex	CR
Hanford	CR	Sandia	CR
Idaho (ID)	CR	Monticello	MR
Nevada Test Site	MR		
Northern New Mexico (NNM)	MR		
Oak Ridge (OR)	MR		
Paducah	CR		
Rock Flats Plant	MR		
Savannah River Site (SRS)			

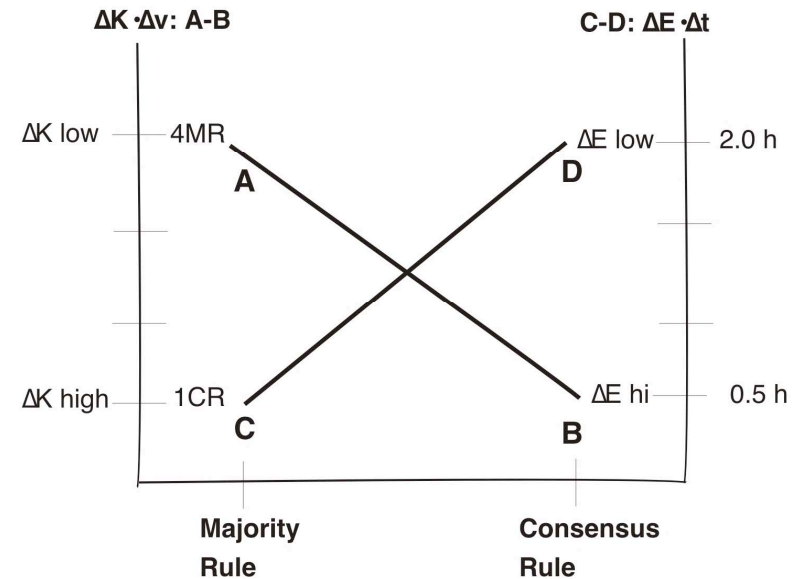
Perturbation: Request by DOE Scientists to adopt plan to accelerate Tru waste shipments to WIPP



- Strategy Uncertainty: Would Boards believe in the plan?
- Execution Uncertainty: Would the Boards vote for the plan?
- Energy Uncertainty: Would Boards expend effort in support?
- Time Uncertainty: Would support by the Boards be timely?

Measurement Problem: A Field Test

The SSAB Transuranic Workshop in Carlsbad, NM, reached consensus Recommendations Regarding Transuranic Waste Characterization across the DOE complex (2003, January; $N=105$). The result: Five of nine Boards returned to their respective sites and approved these Tru waste recommendations (*Majority Rule Boards*: SAB (SRS), Oak Ridge, Paducah, Northern New Mexico; *Consensus Rule Boards*: Rocky Flats Plant); four of the nine Boards disapproved (*Majority Rule Boards*: Nevada Test Site; *Consensus Rule Boards*: Hanford, Fernald, Idaho), giving $\chi^2(1)=2.74$, $p \approx .10$.

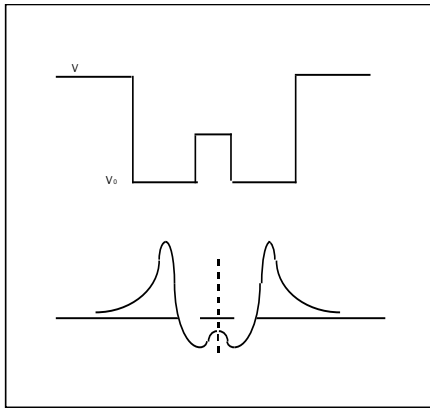


Mathematical interdependence: **A.** MR Boards bring opposing views together to seek the best decision and compromise (ΔK low; Lawless & Schwartz, 2002), generating instrumental action (Δv high; shown: 4 MR Boards agreed, not shown: 1 MR Board did not). **B.** For multiple reasons (ΔK high; Bradbury et al., 2003), CR Boards could not accept the complex request on Tru wastes by the DOE Scientists ($\Delta v \rightarrow 0$; shown: 1 CR Board accepts; not shown: 3 CR Boards do not). **C.** Conflict on MR Boards is intense ($\Delta E \rightarrow \infty$; e.g., Hagoort, 2003; Lawless et al., 2000b) but among few participants and thus short-lived (shown: $\Delta t = 0.5$ hours). **D.** Instead of instrumental action, CR Boards repeatedly restate values (high I , low $K \approx$ boredom $\Rightarrow \Delta E$ low; e.g., HAB, 2003) with many speakers over long and uncertain periods of time (shown: $\Delta t = 2$ hr).

Conclusions

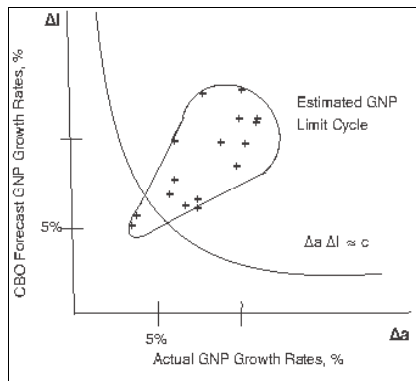
- Groups are at a lower entropy than $\sum x_i$; $M(I,S)$ or $M(G,S) \rightarrow$ classical I , $\sum x_i \neq$ Group
- **Albeit incomplete, the Field Test of the measurement problem is the 1st demonstration of mathematical physics (H.U.P.) between competing organizations**
 - CR \rightarrow values; MR \rightarrow instrumental action
 - $c = h$ for the individual and possibly the group
 - **Social perturbations** (Carley; Lipshitz) \approx **atomic perturbations** (Zeilinger)
- Why use a bistable model?
 - Exploits multiple interpretations of reality
 - Possibly better d.m., control, and autonomy for MAS
 - Possibly more efficient models of social reality

Neutrals ->
Superpositioning



Over time, competition for neutrals forces losers to adapt by “turning” (e.g., Democratic President enacts welfare reform; Republican President encourages Medicare reform)

Fdbk on Eqn (1)?



9th ICCRTS,
Copenhagen, 9/2004

Future Research: Can Superpositioning, Fourier comp. (N), F fcns (S.R.) & fdbk (L.C.'s) solve autonomy?

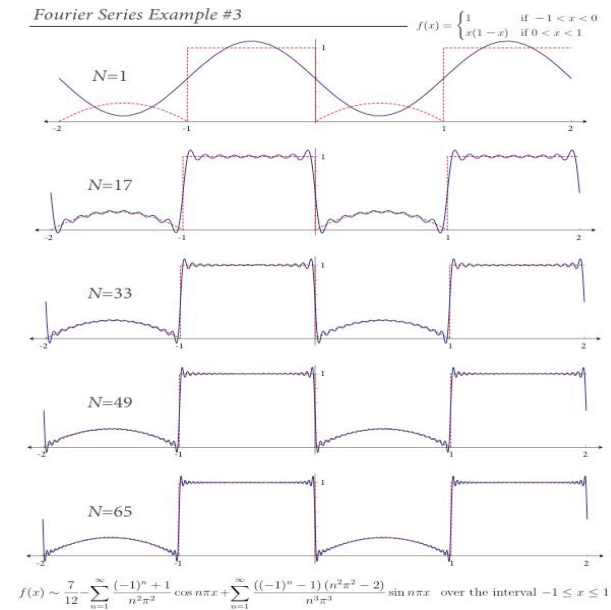
- **Bifurcations:** The double square well model represents E barrier between opponents and neutral middle, overcome in democracy by compromise or persuasion => regulation
- **Stochastic Resonance:** Random “exploration of alternatives”; dI/dt and dX/dt are Kolmogorov coupled nonlinear equations w/ $F_E(t)$ as forcing function => dampening under CDM, self-organization under DDM -> + Fourier components in system (**Emergence; Power**)

• Increasing # of neutrals improves dm

• **Regulatory Control:** +/- Feedback & “turning” produce non-linear limit cycles (**May’s 2001 + fourier components, critical link**)

- Math control theory: can + innovation under CDM by + competition -> instability
- can - innovation under DDM by + cooperation or consensus -> instability
- Grover’s search time $\approx O(n)$ steps v. $O(\sqrt{n})$; complexity $\approx \Delta t$ (Aharonov & Bohr, 1961; Lawless, 2004)

+ Fourier Components -> Emergence



- Representations improve w/+ Fourier components (also, music signals, data mining, system control). Similar to constructing a photograph by adding photons (French & Taylor (1978) Introduction to quantum physics, MIT press, p. 2-10).
- Fourier components reflect + competitive skills, + market gains (e.g., Toyota), and with Δt as the time to respond (as Δt increases, competitive skills lessen)

Additional Reading

- Lawless, W.F., Bergman, M., & Feltovitch, N. (2004, forthcoming), Consensus-seeking versus truth-seeking, ASCE Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management.
- Lawless, W. F., & Grayson, J.M. (2004a). A quantum perturbation model (QPM) of knowledge and organizational mergers. Agent Mediated Knowledge Management. L. van Elst, & Dignum, V. Berlin: Springer-Verlag (pp. 143-161).
- Lawless, W.F. & Grayson, J.M. (2004b). A quantum model of organizations, autonomy, and control, AAAI-04 Spring Symposium, Stanford, Technical Report SS-04-03, pp. 116-121.
- Lawless, W.F. & Chandraskera, R. (2002), Information density functional theory: A quantum approach to adversarial intent, Proceedings AAAI Fall Conference, November 15-17, 2002, MA, pp. 26-31.
- Lawless, W. F., & Schwartz, M. (2002). "The social quantum model of dissonance: From social organization to cultural evolution." Social Science Computer Review (Sage), 20(4), 441-450.
- Lawless, W.F. (2002), Adversarial cooperative collaboration: An overview of social quantum logic, Proceedings Collaborative learning agents, pp. 122-3, AAAI-2002 Spring Symposium, Stanford U.
- Lawless, W.F. (2001). The quantum of social action and the function of emotion in decision-making, Proceedings Emotional Agent II. The Tangled Knot of Cognition, pp. 73-78, AAAI Fall Symposium, Cape Cod, MA, November 2, 2001.
- Lawless, W.F. & Castelao, T. (2001), The University as Decision Center, IEEE Technology and Society Magazine (special issue: University as Bridge Between Technology and Society), 20(2), 6-17.
- Lawless, W.F., Castelao, T., & Abubucker, C.P. (2000b), Conflict as a Heuristic in Development of Interaction Mechanics, In C. Tessier, H.J. Muller, & L. Chaudron, Conflicting agents: Conflict mgt in multi-agent systems, pp. 279-302, Boston: Kluwer).
- Lawless, W.F., Castelao, T., & Ballas, J.A., (2000a), Virtual knowledge: Bistable reality and solution of ill-defined problems, IEEE Systems, Man, & Cybernetics, 30(1), 119-124).